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SENSITIVITY STUDY ON AIR DISPERSION AND HAZARD EXPOSURE MODELS,(U)

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TR-3135-2

SENSITIVITY STUDY ON AIR DISPERSION AND HAZARD EXPOSURE MODELS

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PREFACE

This document was prepared for the U.S. Army Armament Research and Development Command as part of a continuing effort to evaluate the potential hazards associated with the use of depleted uranium munitions. Support for this effort was provided by the Office of the Project Manager, Tank Main Armament Systems, XM1 Tank System Program, Army Contract No. DAAK10-80-C-0108 New The technical monitor was Dr. Ernest W. Bloore, DU Task Force Chairman, U.S. Army Armament Research and Development Command, Dover, New Jersey 07801.

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SECTION I
INTRODUCTION

The U.S. Army is currently using mathematical models designed by The Analytic Sciences Corporation (TASC) to assess potential hazards associated with the use of depleted uranium (DU) munitions. These models simulate dispersion of material released to the air, determine subsequent air and ground concentrations, and estimate potential radiological and toxicological exposures to man from such releases The models provide the Army with a decision-support tool for addressing health and safety considerations associated with depleted uranium released to the air under a range of scheduled or accidental conditions.

When a mathematical representation is used to depict an actual or anticipated event, a number of factors can introduce variability or uncertainty into the model and thereby affect the accuracy and precision of the model estimates. Factors which affect estimates of airborne dispersion of depleted uranium and the resulting hazard exposures include:

- Inherent variability of natural phenomena in the atmosphere (i.e., wind, temperature, stability, etc.) and the ability to depict these processes reliably in time and space.
- "Error" in measured meteorological data due to equipment and analysis limitations, use of averaged values, simplified measurements of complex, dynamic processes, etc.
- Incomplete knowledge of the effects of low-level radiation on man over time.

- Level of detail used to describe physical and biological processes in the models.

To make use of mathematical models effectively and with confidence in decision-making, it is important to know to what extent these variabilities (uncertainties) affect the accuracy and precision of the model output.

Sensitivity analyses are often conducted to determine the degree of uncertainty (range of error) in model estimates that can be expected, given ranges of variability for the model parameters. These analyses broaden understanding of the model dynamics by identifying key parameters and functions and determining the magnitude of their impact on model results, i.e., by estimating the sensitivity of model estimates to the variability of model parameters and functions.

A sensitivity/uncertainty evaluation was performed on the air dispersion and hazard exposure models developed by TASC. The objective of this study was to obtain a clearer understanding of the relationship between model parameters and model estimates so that these models and their results can be used with confidence in decisions regarding health and safety considerations associated with the use of depleted uranium munitions.

In Section II the systematic sensitivity analysis used in this study is described. The model parameters and sensitivity/uncertainty evaluation for the air dispersion models and hazard exposure models are discussed in Section III. Section IV contains the conclusions drawn from the evaluation of model parameters from both the air dispersion and hazard exposure models.

SECTION II
SENSITIVITY ANALYSIS

Sensitivity analysis provides a useful and effective means for obtaining a better understanding of the "cause and effect" relationships between model parameters and model estimates. By varying model parameters (singly and in combination) and keeping the remaining parameters constant, the variability in model estimates due to the uncertainty in each parameter can be approximated. How, and to what degree, changes in parameter values affect model estimates can be defined, and the most critical parameters and functions, which influence these estimates, can be identified. By determining the sensitivity of model estimates to parameter variabilities, expected uncertainties associated with the model estimates can be ascertained.

The simplest measure of sensitivity/uncertainty is the unaveraged deviation of a model estimate from the baseline solution (i.e., the "best" or most representative value for each model parameter). Deviations provide a convenient measure of sensitivity/uncertainty when probability distributions of the model parameters are unknown or not well-defined. When probability distributions of the model parameters are known, statistical measures, such as the mean or variance, better depict the variation of model estimate(s) from the baseline solution and more sophisticated analyses are possible, thereby providing more comprehensive information to identify subtle sensitivities.

Varying model parameters can produce a simple, consistent pattern or considerable variability over time and space. When evaluating the sensitivity of model estimates to variations in parameter values, it is important to consider not only the magnitude and direction of the effect but also the type of changes in specific parameters that have the most dramatic effect and the range over time and space in which the effect occurred.

Sensitivity/uncertainty can be evaluated using a number of methods of analysis. These include: a deterministic approach in which unaveraged deviations are used as measures of sensitivity/uncertainty and the probability distributions of model parameters may or may not be known, and a sampling approach in which the measures of sensitivity/uncertainty are averaged or expected values and the probability distributions of model parameters, if not well-defined, are attained by a reiterative sampling process. Several methods of analysis, and the application of each to air dispersion models, are discussed in Reference 1.

Certain factors should be considered when selecting a method of sensitivity/uncertainty analysis for an evaluation. One consideration is the suitability of the method to the purpose and needs of the evaluation. Another factor is cost; typically a sampling approach is more costly than a deterministic approach. However, the most important consideration is the ability of the user to understand and interpret the results of the analysis. Simple, conceptually intuitive methods are readily understood and interpretable by most users, and often provide as much useable information as the more sophisticated approaches which require greater skill, effort, and cost to implement effectively.

The random trial method of analysis was used for the sensitivity/uncertainty evaluations of TASC's air dispersion and hazard exposure models. This method is widely employed because it is logically and intuitively clear to most investigators and is flexible for use in a variety of model applications. The effect of all model parameters, including those which are time-dependent, can be evaluated, and the probability distributions of model parameters are not required to implement the analysis. This method can be used alone or in conjunction with more sophisticated analyses.

A random trial analysis is conducted by varying the values of each model parameter (singly or in combination) over the expected range of its distribution while keeping the remaining parameters at their baseline values and noting the resulting change in model outputs. The unaveraged deviations are measures of the model sensitivities. The extent to which these deviations effectively depict the variability/uncertainty of model estimates over time and space depends on how comprehensively the analysis is implemented. Measures of sensitivity can be determined relatively economically using as few as three trial values (high, baseline, and low) from the probable range of values for each parameter. By increasing the number of trial values, a more accurate and precise depiction of the variability (uncertainty) in model estimates over time and space can be obtained. Depending on the skill and experience of the investigator, this method can be as effective, and less costly, in determining sensitivities and uncertainties as the more analytically sophisticated approaches.

SECTION III
SENSITIVITY/UNCERTAINTY EVALUATION

This section contains a discussion of the sensitivity/uncertainty evaluation of the air dispersion and hazard exposure models developed by TASC. The air transport models simulate the dispersion of material released to the lower atmosphere from point sources, wherein the cloud of released material is assumed to rise and expand about its center as it is transported by the prevailing wind and atmospheric stability. Airborne concentrations diminish as distance downwind increases due to dispersion and depletion by deposition. In Reference 2, the model equations for simulating plume and puff releases under both constant and random wind conditions are described.

Hazard exposure models are used in combination with the air dispersion models to estimate the potential radiological and toxicological exposures to man from airborne releases of depleted uranium material. The hazard indices include: whole-body dose, critical-organ dose, and radiological concentration of DU in air for evaluating radiation exposure, and concentration of soluble DU in air for assessing chemical toxicity burden. The model equations for determining these hazard exposures are described in Reference 2, with contributions due to inhalation, resuspension, and/or deposition identified in each expression.

A. MODEL PARAMETERS

1. Air Dispersion Model Parameters

The sensitivity of hazard exposure estimates due to varying air dispersion parameters was evaluated using the following four measures:

- Release height, h
- Deposition velocity, v_d
- Atmospheric stability class, p
- Average wind speed, $\bar{u}$

All model descriptors can be defined in terms of one or more of these basic parameters, and are affected by the variabilities and uncertainties associated with each. Release height and average wind speed are expressed directly in the model equations. Expansion of the cloud in the vertical and crosswind directions (i.e., standard deviations) is a function of stability class and wind speed at downwind distances. The depletion factor is determined by the standard deviations (i.e., stability class and wind speed), release height, and deposition velocity at each downwind distance. The deposition velocity is also a parameter element in the hazard exposure models (in which resuspension of deposited air concentrations is represented); the effect of this parameter on hazard exposure estimates is the combined effect from both models.

The wind rose factor, which appears in the random wind models, represents the frequency of the prevailing winds in a given direction(s) for each wind speed and stability class. Since an increase or decrease in the wind rose factor will produce an equivalent effect on all model estimates in time

and space, this factor was not included in the sensitivity analysis.

The following effects, varying air dispersion model parameters singly and in combination, were evaluated in this sensitivity study:

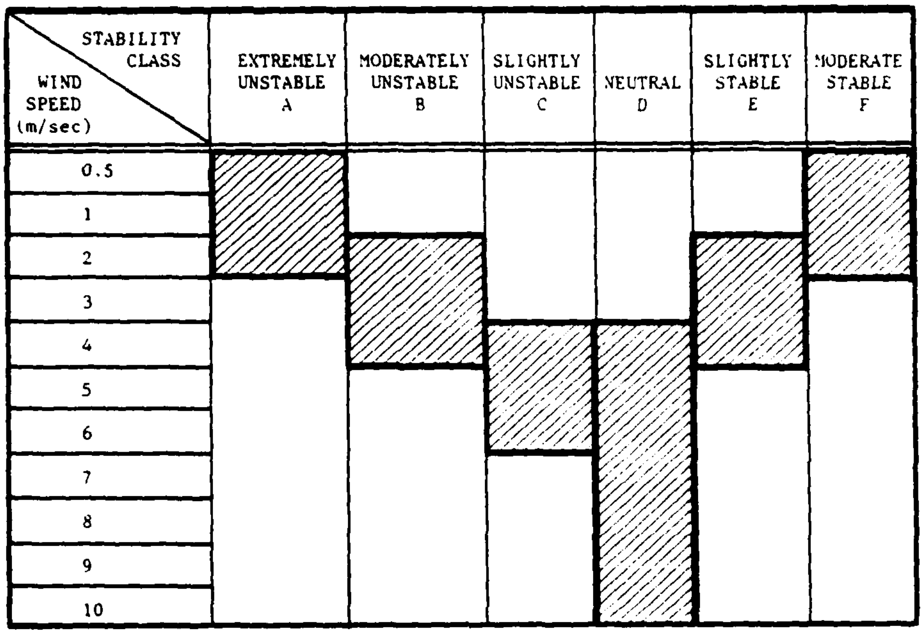
- <u>Single Effects</u>
  - h - release height
  - v_d - deposition velocity
  - $p:\bar{u}$ - average wind speed within stability class
- <u>Combined Effects</u>
  - h, v_d
  - h, $p:\bar{u}$
  - v_d, $p:\bar{u}$
  - h, v_d, $p:\bar{u}$

Note that stability class and wind speed are treated as a nested parameter effect. These parameters are linked implicitly in nature. The impact of stability and wind speed on air concentrations is reflected more accurately when this linked (nested) relationship is considered. In Table 1, the association between stability class and wind speed is illustrated.

The trial values that were used in this study to ascertain single and combined effects of varying air dispersion parameters are given in Tables 2 and 3. For each parameter effect, three trial values (high, baseline, and low) were selected from a probable range of values; it is assumed that these values are contained within the probability distribution

TABLE 1

RELATIONSHIP OF STABILITY CLASS AND WIND SPEED



Source: Reference 3.

TABLE 2

TRIAL VALUES FOR MODEL PARAMETERS
(Air Dispersion Models)

PARAMETER \ VALUE	LOW	BASELINE	HIGH	SOURCES/COMMENTS
Release height, h (m)	0.0	5.0	10.0	---
Deposition velocity, v_d (m/sec)	0.0001	0.01	0.1	low: slow depletion base: Reference 4 high: particle size $\simeq$ 20 μm AED
Wind speed within stability class, $p:u$ (m/sec)	A:1	D:8	F:1	Reference 3

TABLE 3
TRIAL VALUES FOR WIND SPEED WITHIN STABILITY

STABILITY CLASS	AVERAGE WIND SPEED (m/sec)		
	LOW	BASELINE	HIGH
A Low	0.5	1	2
B	2	3	4
C	4	5	6
D Baseline	4	8	10+
E	2	3	4
F High	0.5	1	2

Source: Reference 3

for each measure. The baseline value corresponds to the "best" or most representative value for each parameter (which is not necessarily an average value). The high and low values are selected near the endpoints in the possible range of values.

2. Hazard Exposure Model Parameters

The sensitivity of exposure estimates to varying parameter values in the hazard exposure models was evaluated using the following measures:

- Resuspension factor, K_r
- Fraction aerosolized, f_a
- Fraction respirable, f_b

- Duration of exposure, $T_{k\ell}$
- Amount available for dispersal, N_ℓ
- Amount contributing to ground concentration, M_ℓ
- Specific activity of DU, A_i
- Internal dose commitment factor, DFI_{ij}

and

- v_d, K_r (previously defined)

The effects of two model parameters -- breathing rate, B_k, and external dose commitment factor, DFD_{ij} -- were not included in this evaluation. These parameters are generally treated as constant measures when determining hazard exposures (values for each parameter are given in Tables 4 and 5).

The hazard exposure parameters were evaluated using three trial values (high, baseline, and low) from the probable range of values for each parameter; it is assumed that these are representative values contained within the probability distribution of each measure. The trial values that were used to assess the parameter effects are listed in Tables 4 and 5.

B. DISCUSSION OF RESULTS

The sensitivity/uncertainty of hazard exposure estimates was evaluated using the random trial method described in Section II. Parameter effects were determined by systematically varying the values of each model parameter (singly or in combination) while holding the remaining measures constant at their baseline values.

TABLE 4

TRIAL VALUES FOR MODEL PARAMETERS
(Hazard Exposure Models)

PARAMETER \ VALUE	LOW	BASELINE	HIGH	SOURCES/COMMENTS
Resuspension factor, K_r (1/m)	1.0×10^{-10}	1.0×10^{-6}	1.0×10^{-2}	Reference 5
Fraction Aerosolized, f_a	0.07	0.35	0.70	low: --- base: --- high: Reference 6
Fraction Respirable, f_b	0.10	0.30	0.56	low: --- base: --- high: Reference 6
Duration of Exposure, $T_{k\ell}$ (sec)	7.86×10^{6}	1.57×10^{7}	3.15×10^{7}	low: 91 24-hr days base: 182 24-hr days high: 365 24-hr days
Amount Available for Dispersal, N_ℓ (kg)	200	500	1000	---
Amount Contributing to Ground Concentration, M_ℓ (kg)	200	500	1000	---
Breathing Rate, B_k (m^3/sec)	--	2.32×10^{-4}	--	Reference 7

TABLE 5

TRIAL VALUES PER URANIUM ISOTOPE FOR MODEL PARAMETERS (Hazard Exposure Models)

PARAMETER	BODY ORGAN	ISOTOPE	VALUE			SOURCES/COMMENTS
			LOW	BASELINE	HIGH	
Specific Activity of DU, A_i (Ci/kg)		^{234}U	0.0	2.24×10^{-5}	3.03×10^{-5}	low: Reference 8
		^{235}U	4.28×10^{-6}	5.35×10^{-6}	5.35×10^{-6}	base: Reference 2
		^{238}U	3.32×10^{-4}	3.32×10^{-4}	3.32×10^{-4}	high: Reference 9
Dose Commitment factor for internal exposure (acute or chronic) to air concentrations, DFI_{ij} (rem/Ci)	Whole Body	^{234}U	--	6.46×10^{5}	7.81×10^{6}	base: Reference 10 (Reference Man Model)
		^{235}U	--	6.07×10^{5}	8.84×10^{6}	
		^{238}U	--	5.67×10^{5}	8.76×10^{6}	
	Critical Organ (Lungs)	^{234}U	--	5.22×10^{7}	2.73×10^{8}	high: Reference 11 (Task Group Lung Model)
		^{235}U	--	4.90×10^{7}	2.47×10^{8}	
		^{238}U	--	4.58×10^{7}	2.47×10^{8}	
Dose commitment factor for chronic external exposure to ground concentrations, DFD_{ij} $\left(\frac{rem/sec}{Ci/m^2}\right)$	Whole Body & Critical Organ (Lungs)	^{234}U	--	2.03×10^{-6}	--	Reference 10
		^{235}U	--	3.65×10^{-4}	--	
		^{238}U	--	9.77×10^{-4}	--	

The sensitivity evaluations in this study were performed using a constant-wind plume model to ascertain air concentrations of depleted uranium material at downwind locations. Analytically, the air dispersion models (puff or plume, constant or random wind) are similar. The use of a puff model will result in higher, more conservative air concentrations than a plume model since a puff tends to expand and diffuse particles more slowly than a plume. A constant-wind model (puff or plume) will yield more conservative results than its random-wind counterpart since random-wind models allow for variations in the wind. Concentration profiles from these models are given in Figure 1 for comparison.

For each sensitivity analysis, general populace exposure estimates for all four hazard indices (i.e., whole-body dose, critical-organ dose, radiological concentration of DU in air, and toxicological concentration of soluble DU in air) were evaluated and compared. The shape of the exposure profiles and the pattern of variability among trial parameter values were similar for each hazard index considered. For brevity, the following discussion of expected effects on exposure estimates due to variations (uncertainties) in parameter values will be limited to an evaluation of whole-body dose. The resulting conclusions are applicable to all the hazard indices.

The effect on exposure estimates due to varying release height, deposition velocity, and release height and deposition velocity in combination is shown in Figures 2, 3, and 4, respectively. Variations in parameter values for release height have an insignificant effect on exposure estimates (Figure 2). Only small changes occur in the exposure estimates when deposition velocity is varied from the baseline value (0.01 m/sec) (Figure 3). The rate of change in exposure estimates decreases at a faster rate as downwind distance increases when deposition

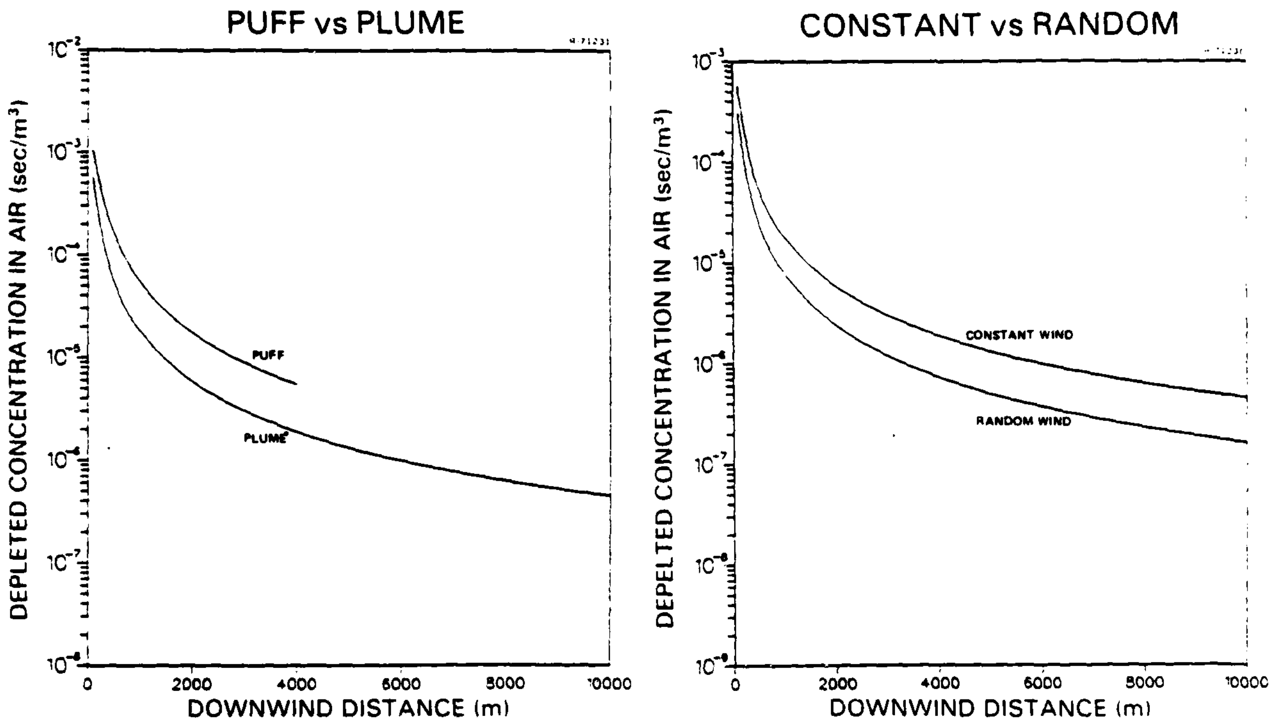


Figure 1   Concentration Profiles of Air Dispersion Models

velocities are higher than the baseline value. When release height and deposition velocity are varied simultaneously (Figure 4), the effect on exposure estimates is similar to that which occurs when the deposition velocity is varied alone. Any effect on exposure estimates from the interaction between release height and deposition velocity is insignificant.

Figures 5 through 8 graphically illustrate the effects on exposure estimates that result when the nested parameter of stability class and wind speed is varied alone or in combination with other parameters in the air dispersion models. Estimates of exposure increase as atmospheric stability conditions change from unstable (A) to stable (F) (Figure 5). When slightly stable (E) and moderately stable (F) conditions prevail, the

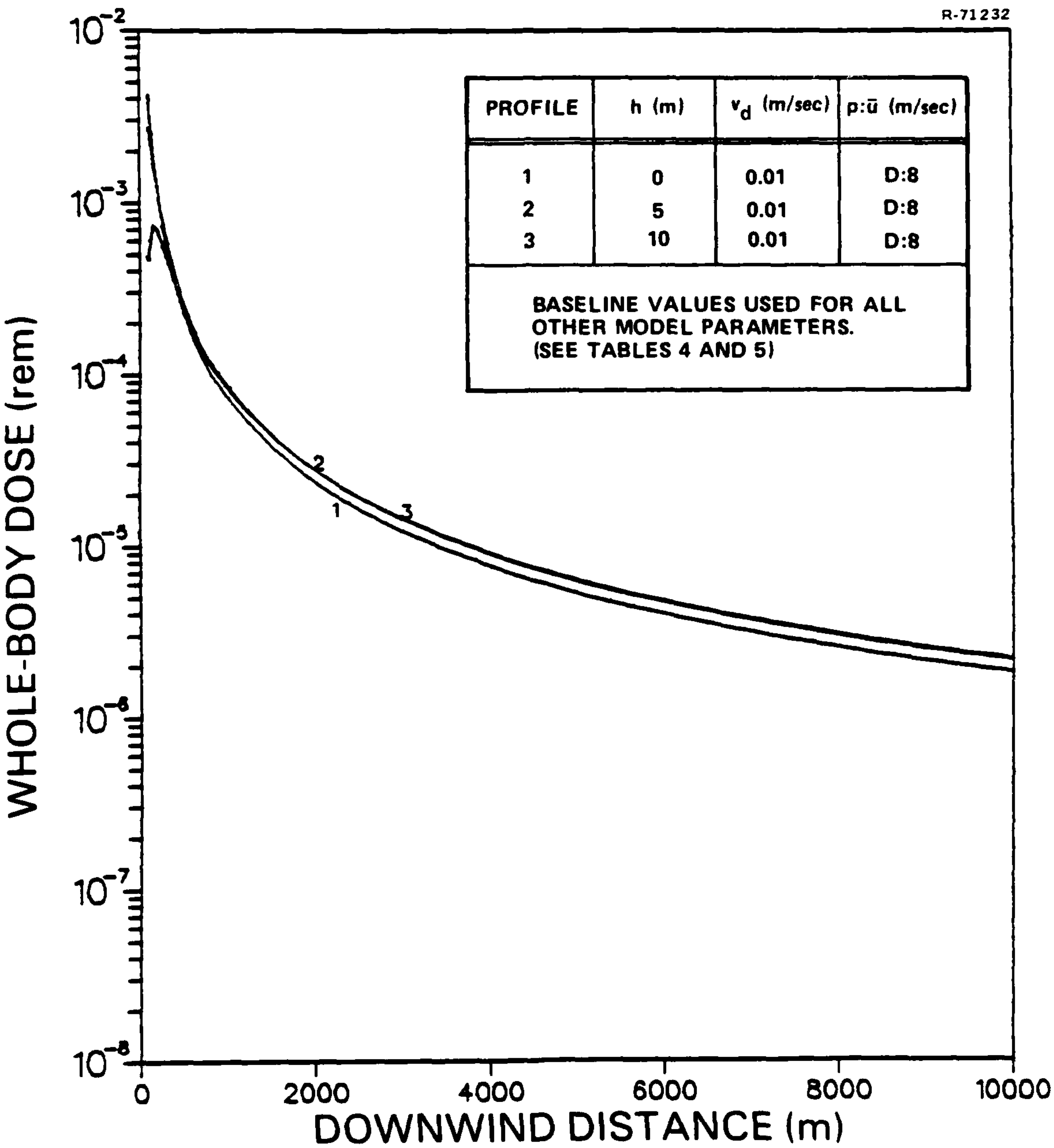


Figure 2 The Effect of Varying Release Height on Exposure Estimates

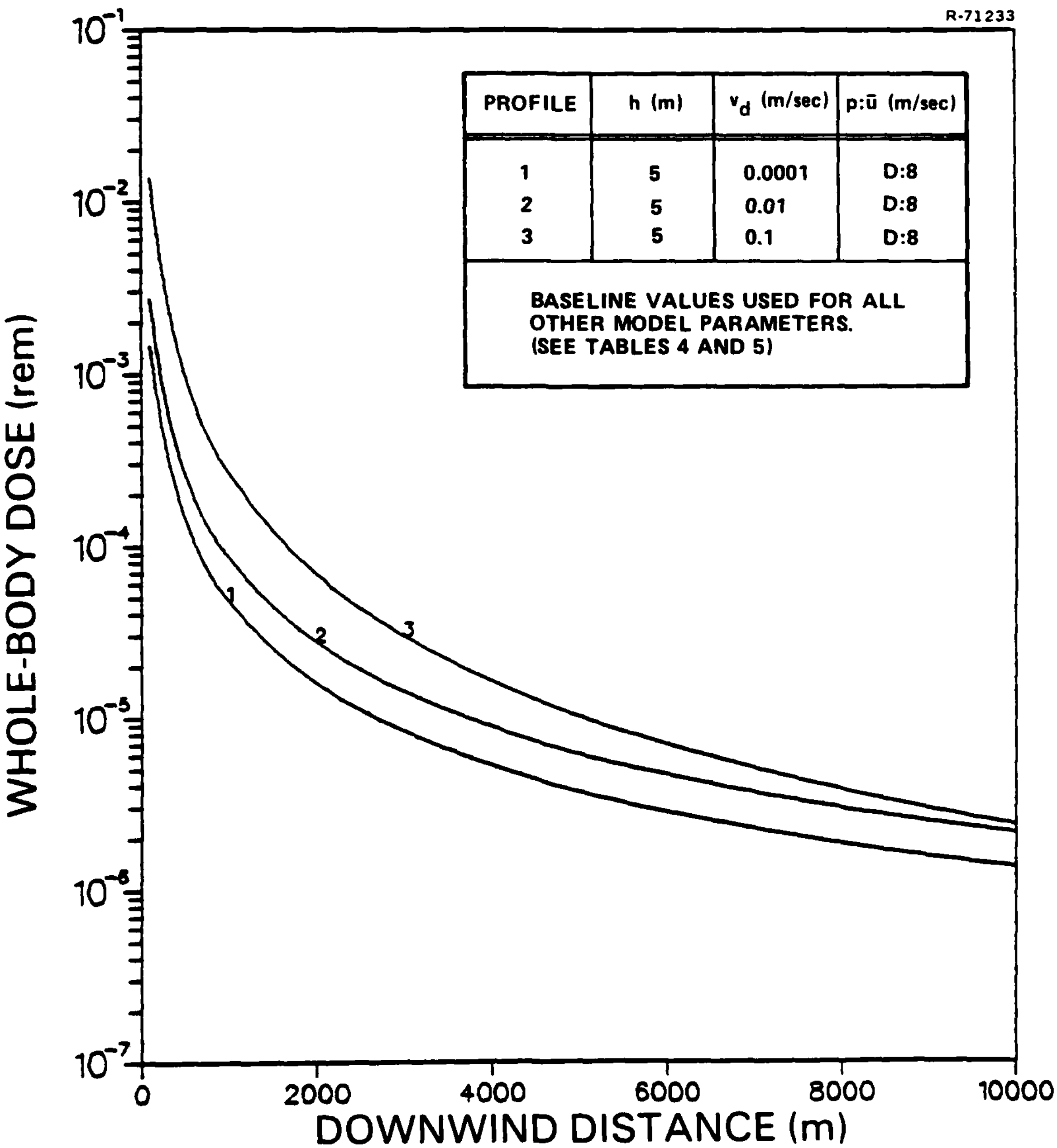


Figure 3 The Effect of Varying Deposition Velocity on Exposure Estimates

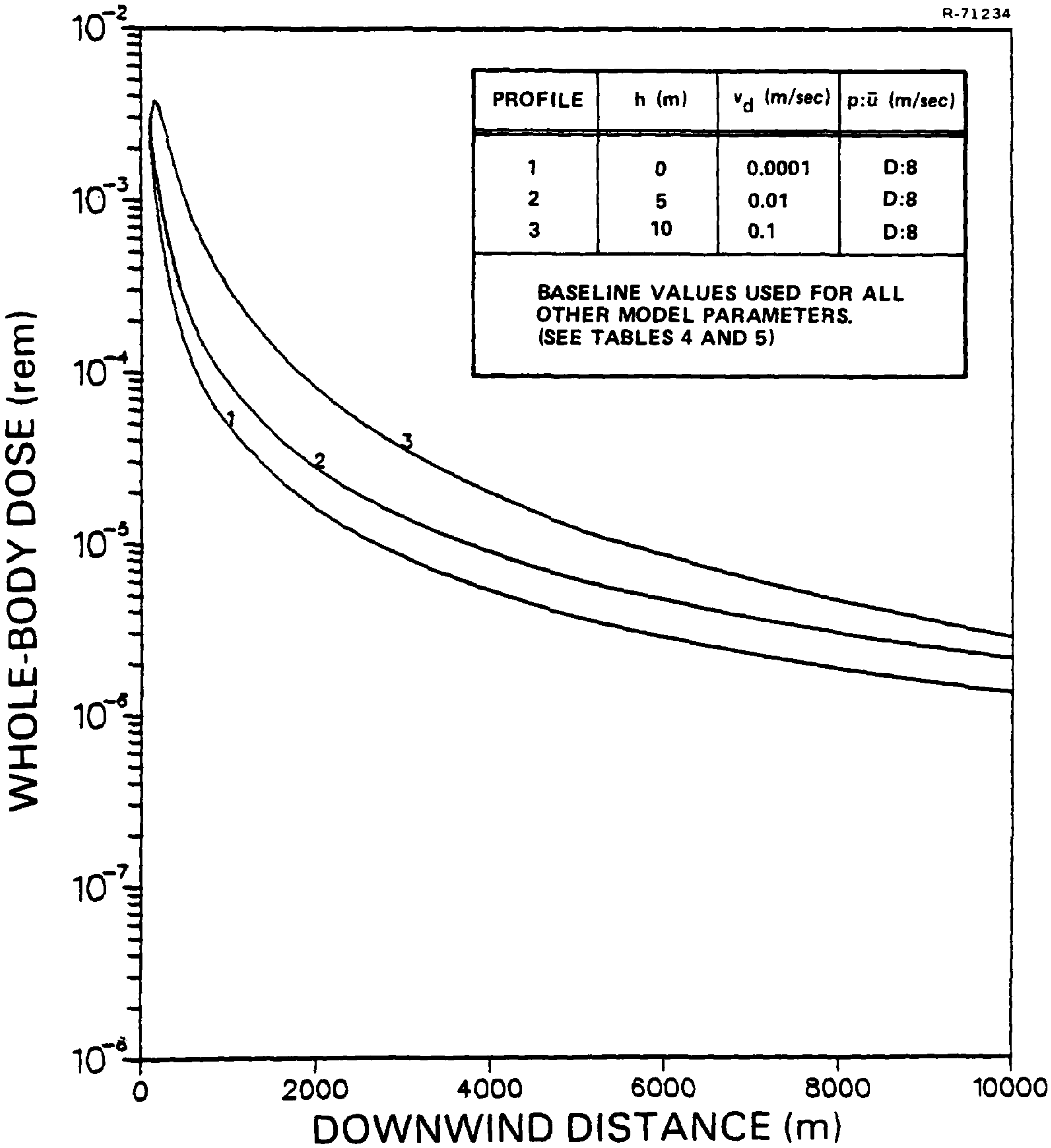
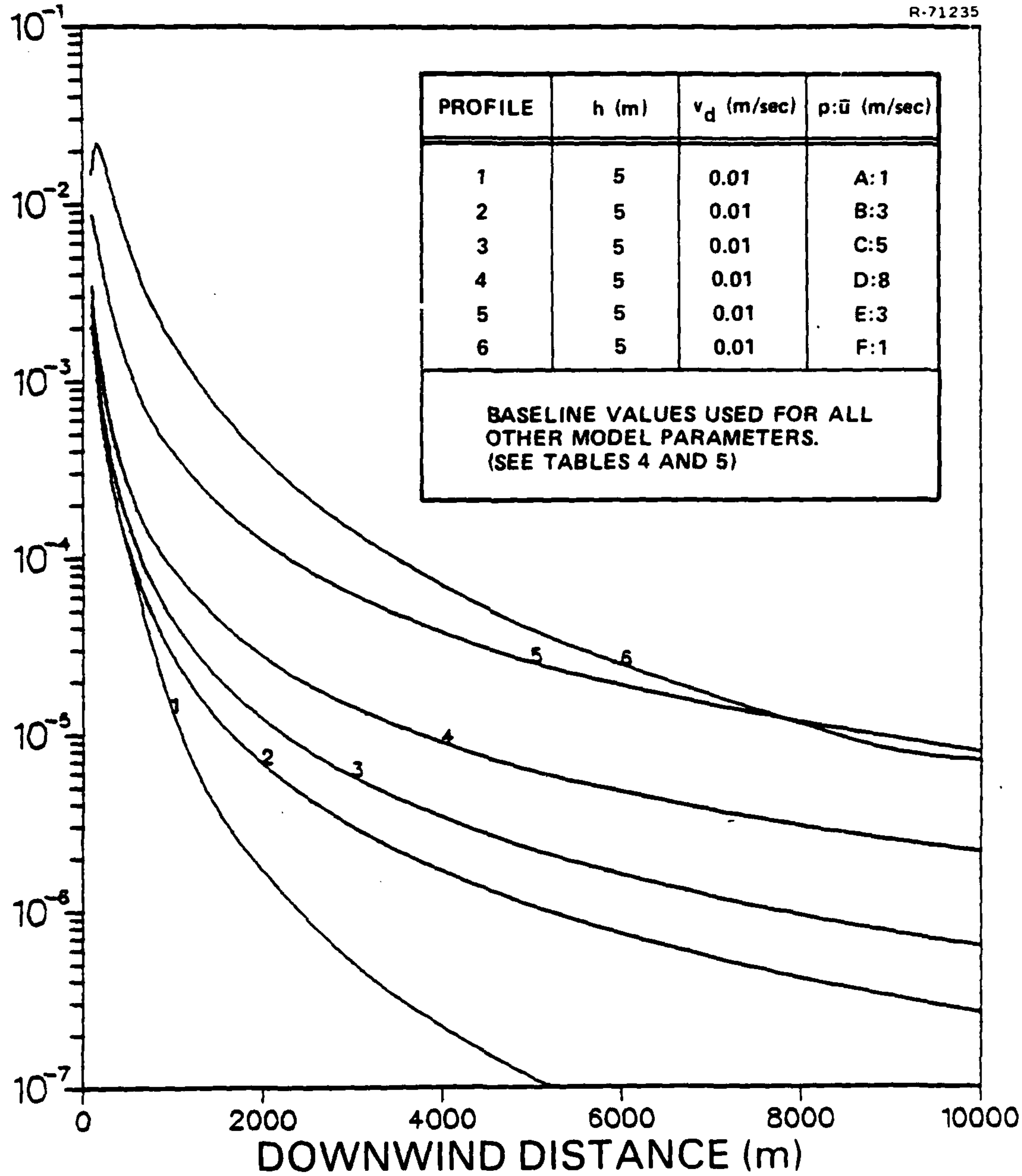


Figure 4 The Effect of Varying Release Height and Deposition Velocity on Exposure Estimates



PROFILE	h (m)	v_d (m/sec)	p:ū (m/sec)
1	5	0.01	A:1
2	5	0.01	B:3
3	5	0.01	C:5
4	5	0.01	D:8
5	5	0.01	E:3
6	5	0.01	F:1

Figure 5 The Effect of Varying Stability Class:Wind Speed on Exposure Estimates

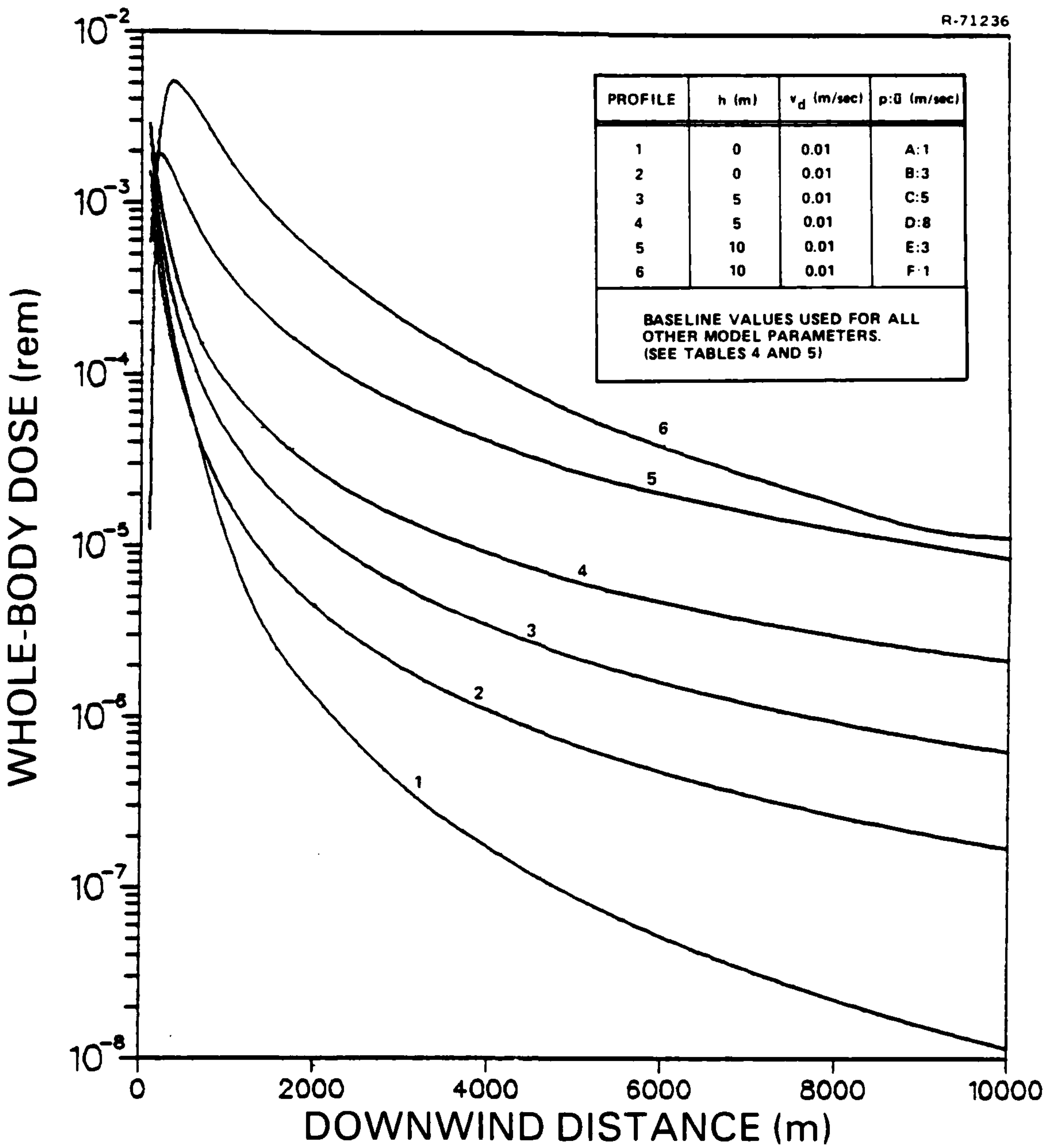


Figure 6 The Effect of Varying Release Height and Stability Class:Wind Speed on Exposure Estimates

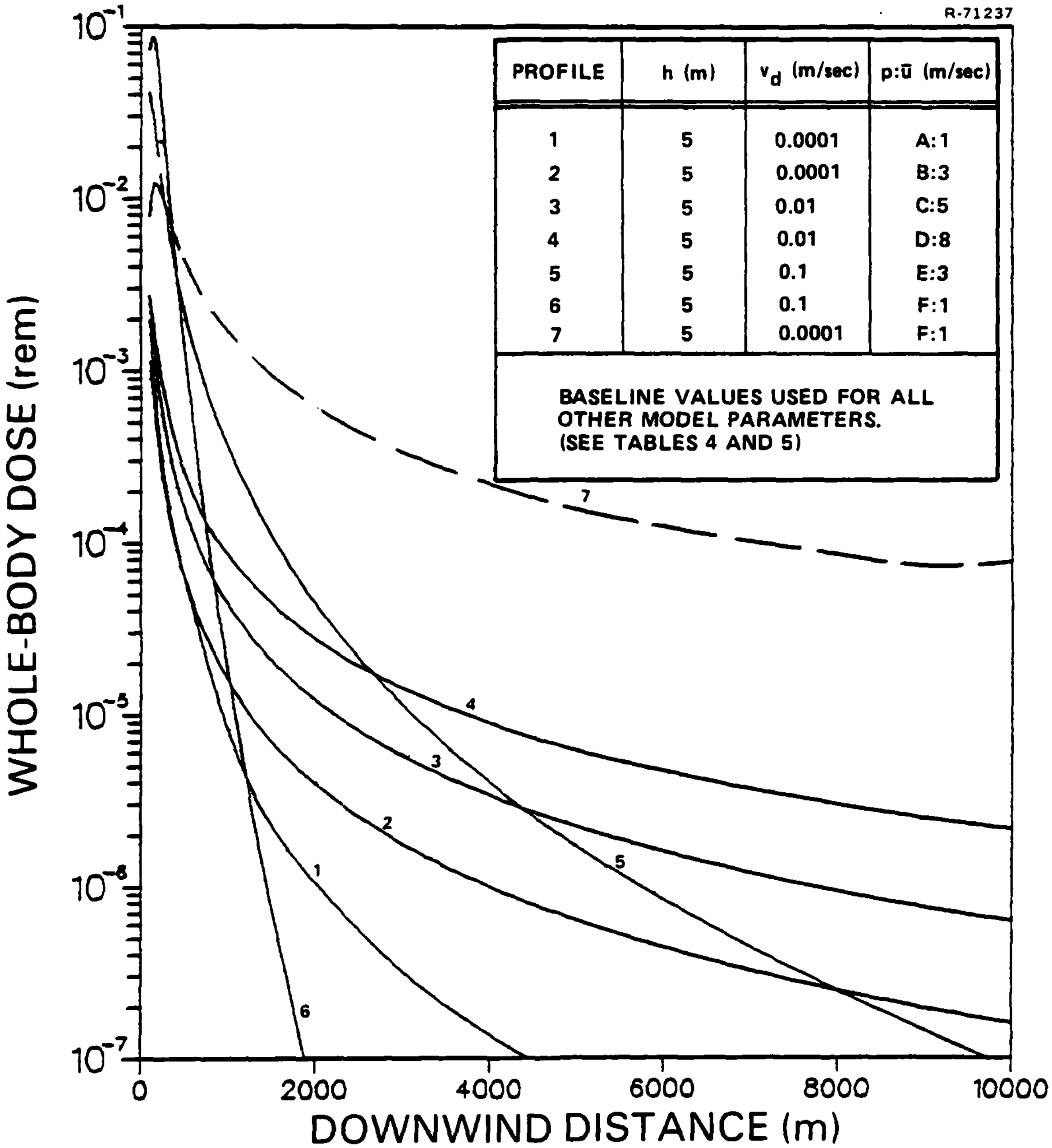


Figure 7 The Effect of Varying Deposition Velocity and Stability Class:Wind Speed on Exposure Estimates

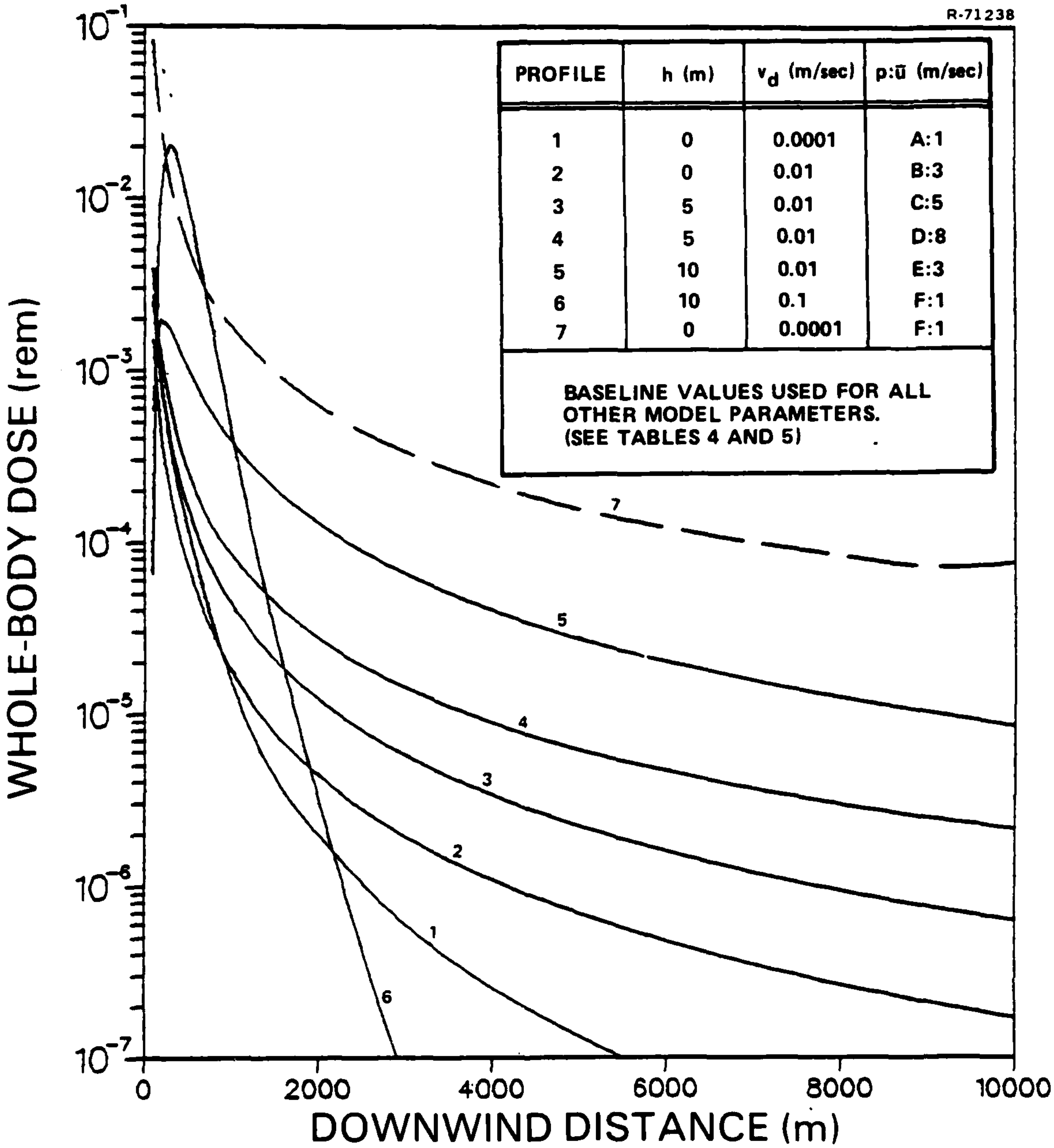


Figure 8 The Effect of Varying Release Height, Deposition Velocity, and Stability Class:Wind Speed on Exposure Estimates

differences in exposure estimates become insignificant as downwind distance increases. When stability class:wind speed and release height are varied in combination (Figure 6), the effect on exposure estimates is similar to that which results when stability class:wind speed is varied singly; any interaction effects which occur are insignificant.

The interaction of deposition velocity with stability class:wind speed (Figure 7) and with stability class:wind speed and release height (Fiure 8) has a significant affect on exposure estimates when the deposition velocity is greater than the baseline value of 0.01 m/sec and stable (E and F) atmospheric conditions prevail. A dramatic decrease in exposure estimates results due to the rapid depletion of aerosolized particles in a stable atmosphere. Under less stable (A-D) atmospheric conditions, the impact of high deposition velocities on exposure estimates is small. When the deposition velocity is less than or equal to the baseline value, interaction effects are insignificant for all stability conditions except the most stable (F); resulting exposure estimates (A-E stability) are similar to that which occurs when stability class:wind speed is varied alone. Exposure estimates were obtained for stable (F) atmospheric conditions and a low deposition velocity of 0.0001 m/sec (dashed lines in Figures 7 and 8); this interaction produces higher, more conservative exposure estimates.

Slight changes in exposure estimates occur as the resuspension factor is varied between baseline (10^{-6}) and low (10^{-10}) values (Figure 9); a high value (10^{-2}) for the resuspension factor will cause exposure estimates to increase significantly. When the resuspension factor and deposition velocity are varied simultaneously (Figure 10), the resuspension factor dominates, producing results similar to those which occur when

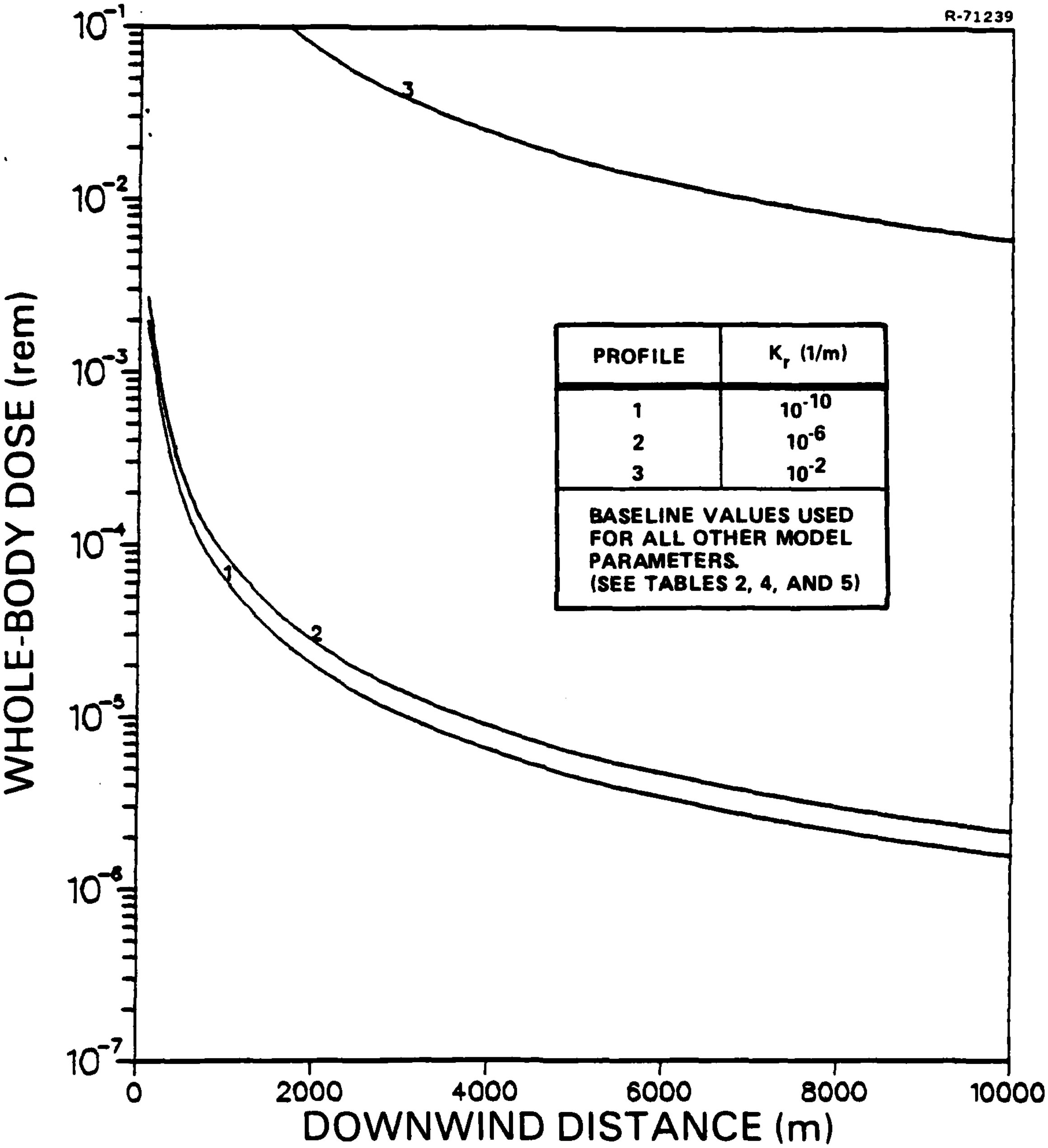


Figure 9 The Effect of Varying Resuspension Factor on Exposure Estimates

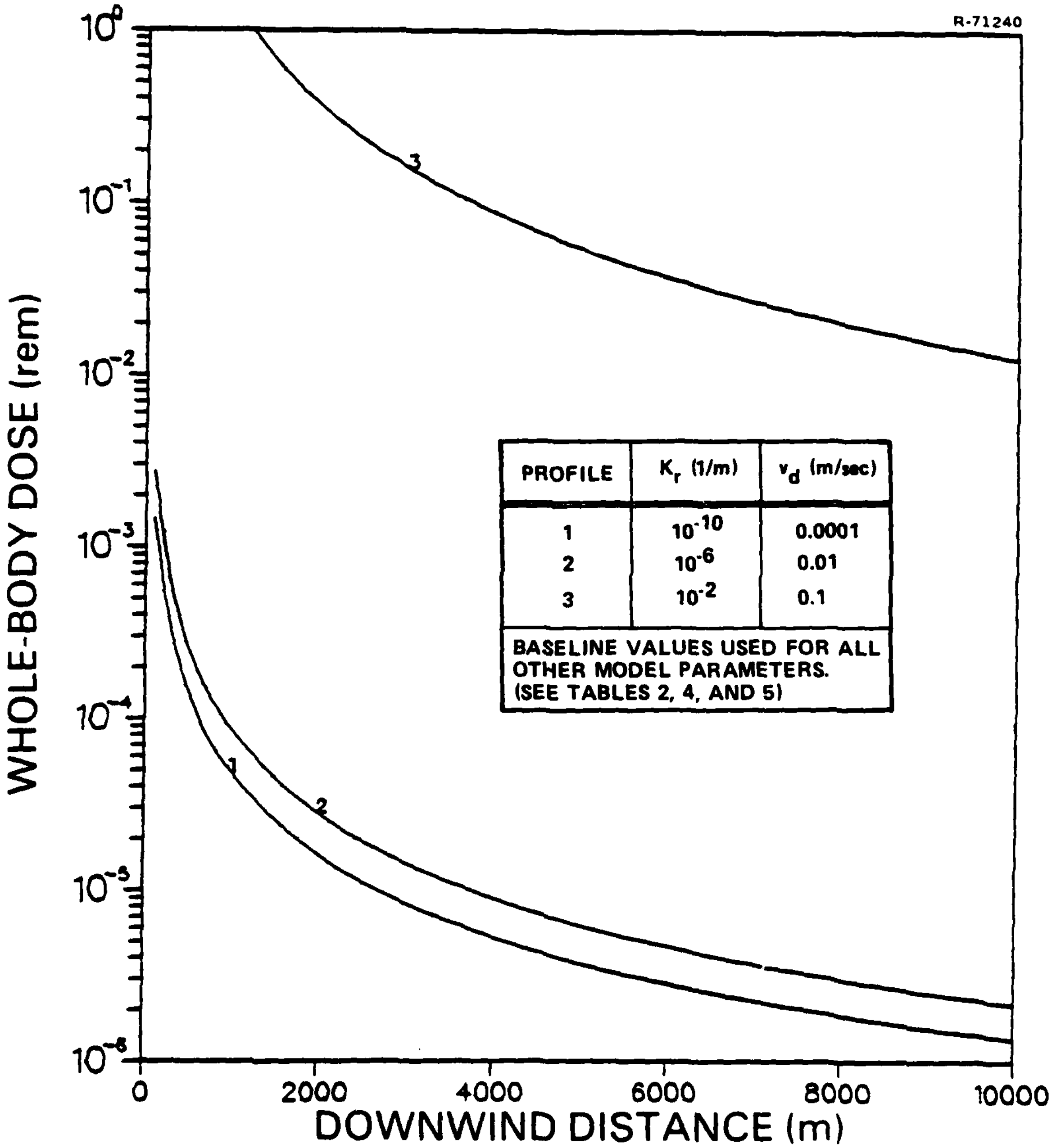


Figure 10 The Effect of Varying Resuspension Factor and Deposition Velocity on Exposure Estimates

the resuspension factor is varied alone. The effect on exposure estimates from the interaction of these two parameters is most significant when both the resuspension factor and deposition velocity are large.

In Figure 11 through 17, the effects on exposure estimates from the remaining parameters in the hazard exposure models are depicted. Variations in parameter values for specific activity of DU have an insignificant effect on the exposure estimates (Figure 11). Approximately a factor-of-10 increase in the exposure estimates results between the baseline (Reference Man Model) and high (Task Group Lung Model) parameter values considered for the internal dose commitment factor (Figure 12) and for the fraction of DU particles that are aerosolized (Figure 13). Only slight changes occur in the exposure estimates when the fraction of respirable particles, duration of exposure, amount of DU available for dispersal, and amount of DU contributing to ground concentration are varied from the baseline measure (Figures 14 through 17).

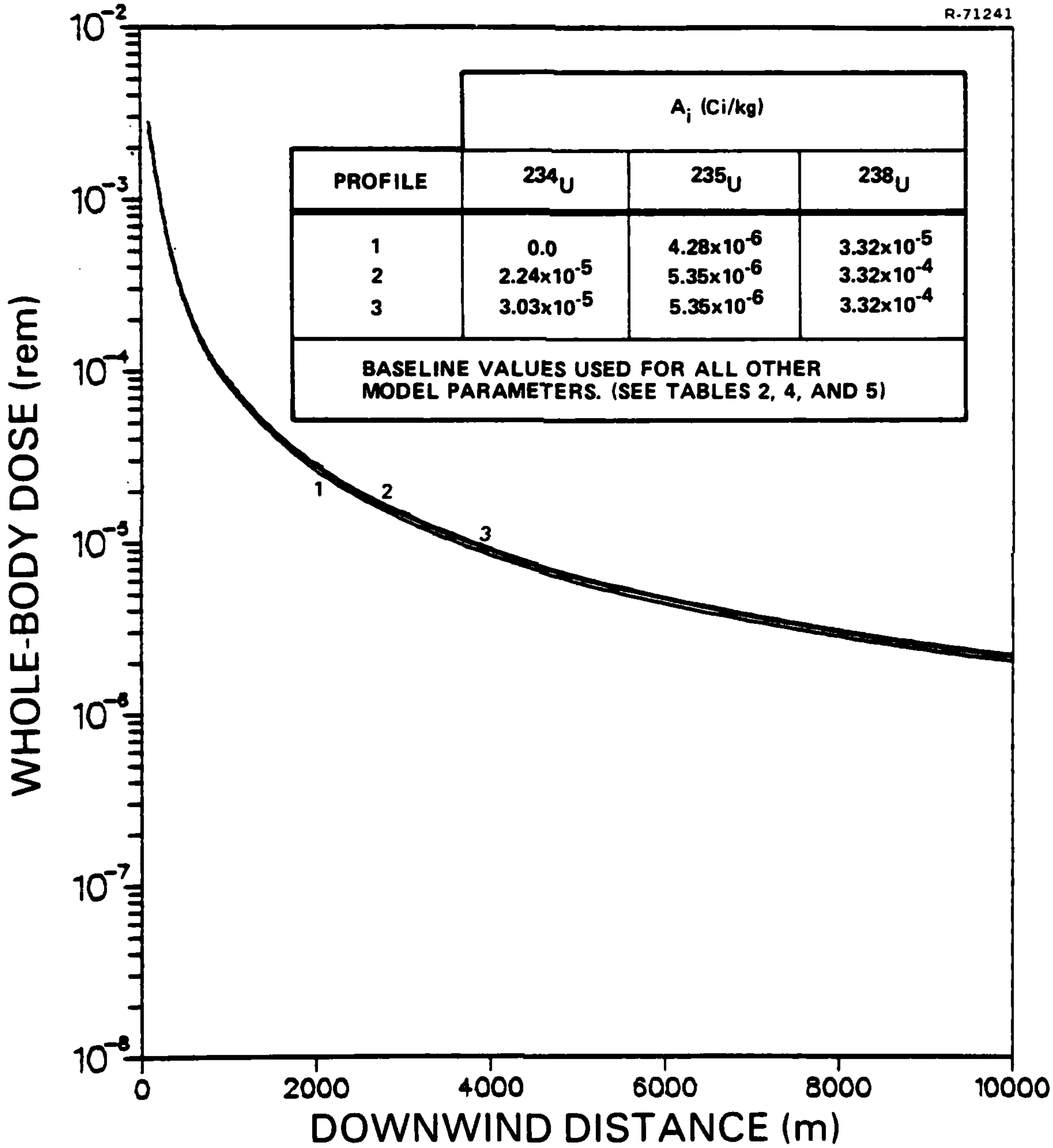
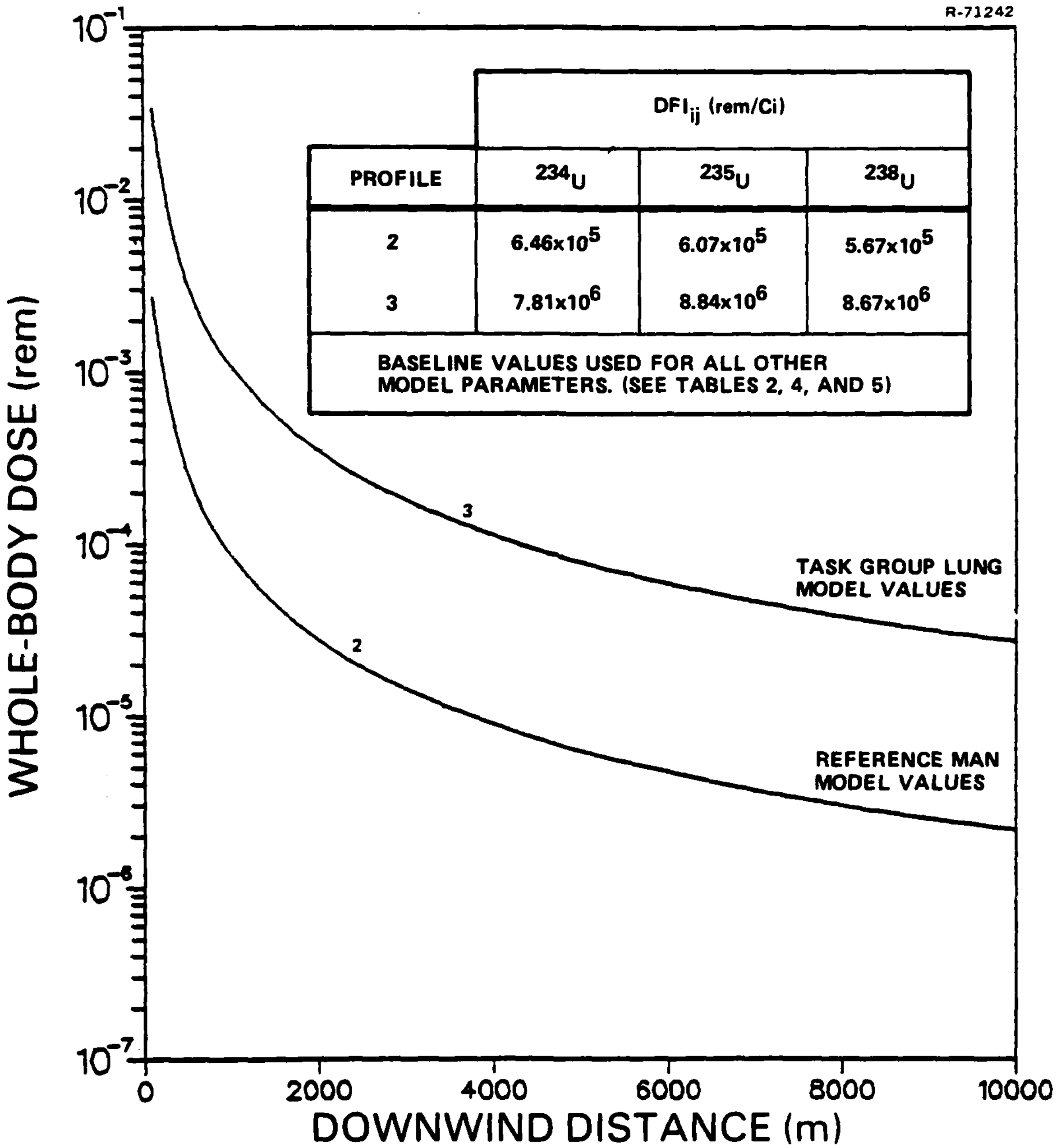


Figure 11 The Effect of Varying Specific Activity of DU on Exposure Estimates



	DFI_{ij} (rem/Ci)		
PROFILE	^{234}U	^{235}U	^{238}U
2	6.46×10^{5}	6.07×10^{5}	5.67×10^{5}
3	7.81×10^{6}	8.84×10^{6}	8.67×10^{6}
BASELINE VALUES USED FOR ALL OTHER MODEL PARAMETERS. (SEE TABLES 2, 4, AND 5)			

Figure 12 The Effect of Varying Internal Dose Commitment Factor on Exposure Estimates

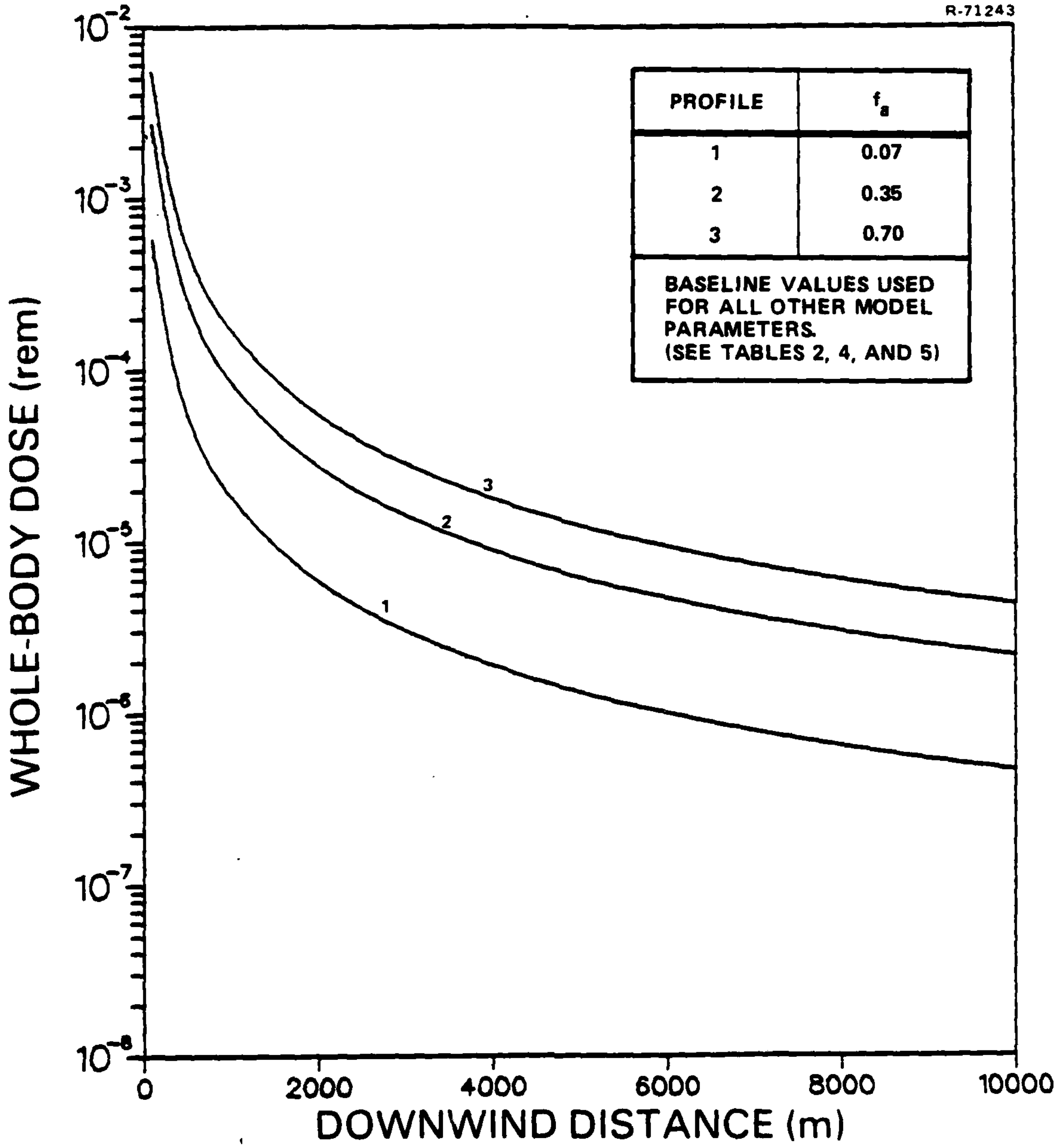


Figure 13 The Effect of Varying Fraction of Aerosolized Particles on Exposure Estimates

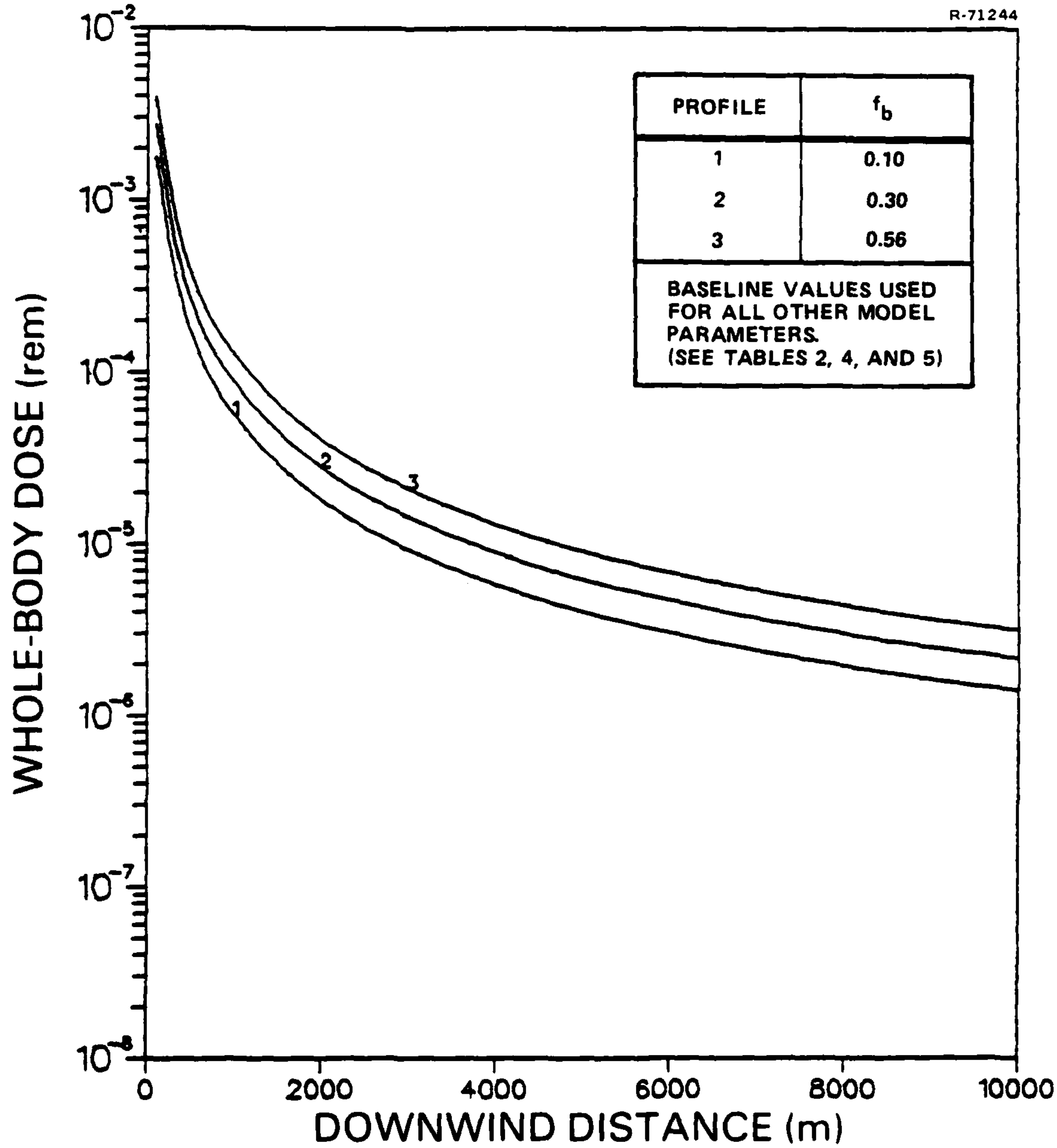


Figure 14 The Effect of Varying Fraction of Respirable Particles on Exposure Estimates

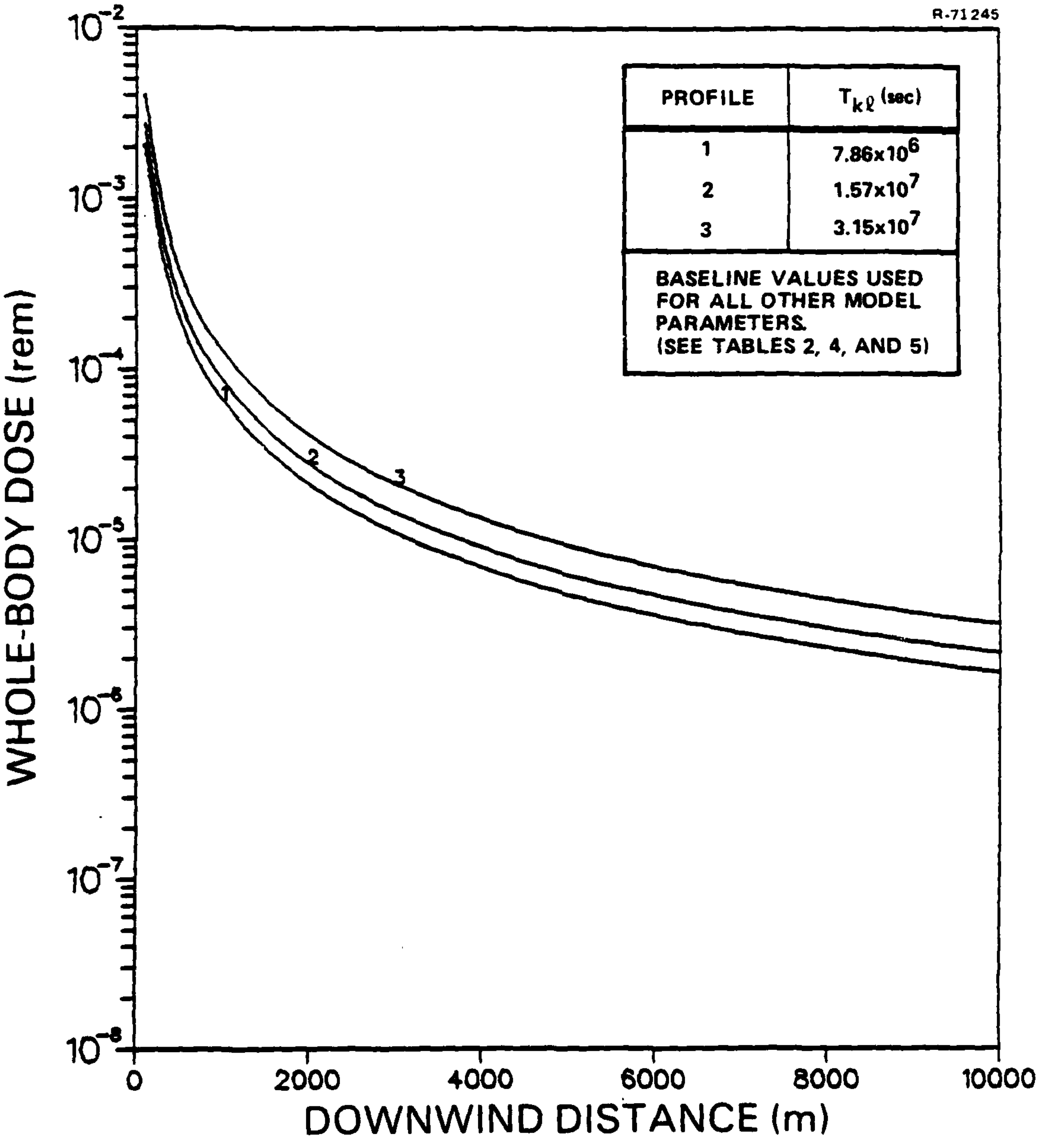


Figure 15 The Effect of Varying Duration of Exposure on the Exposure Estimates

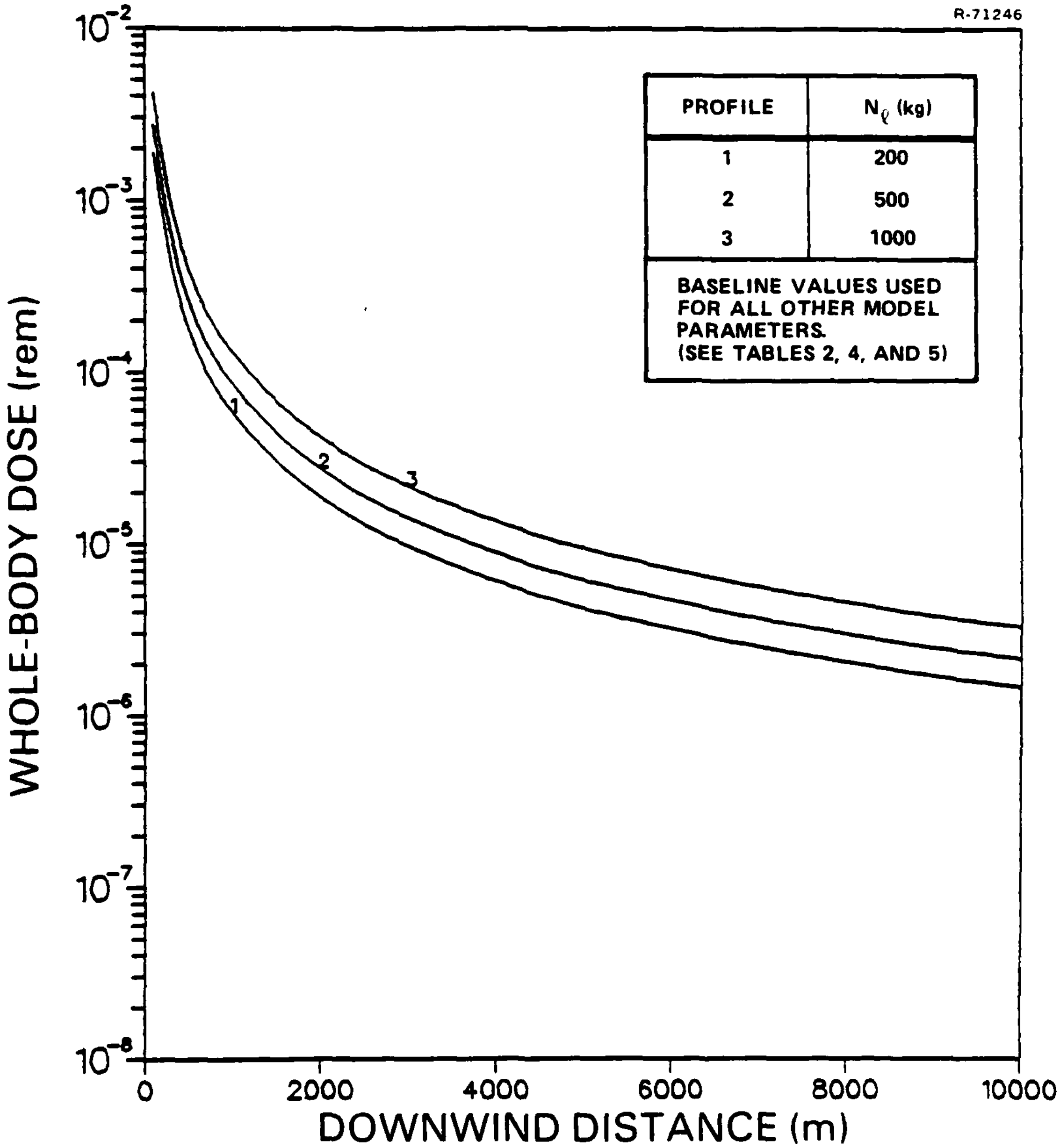


Figure 16 The Effect of Varying Amount of DU Available for Dispersal on Exposure Estimates

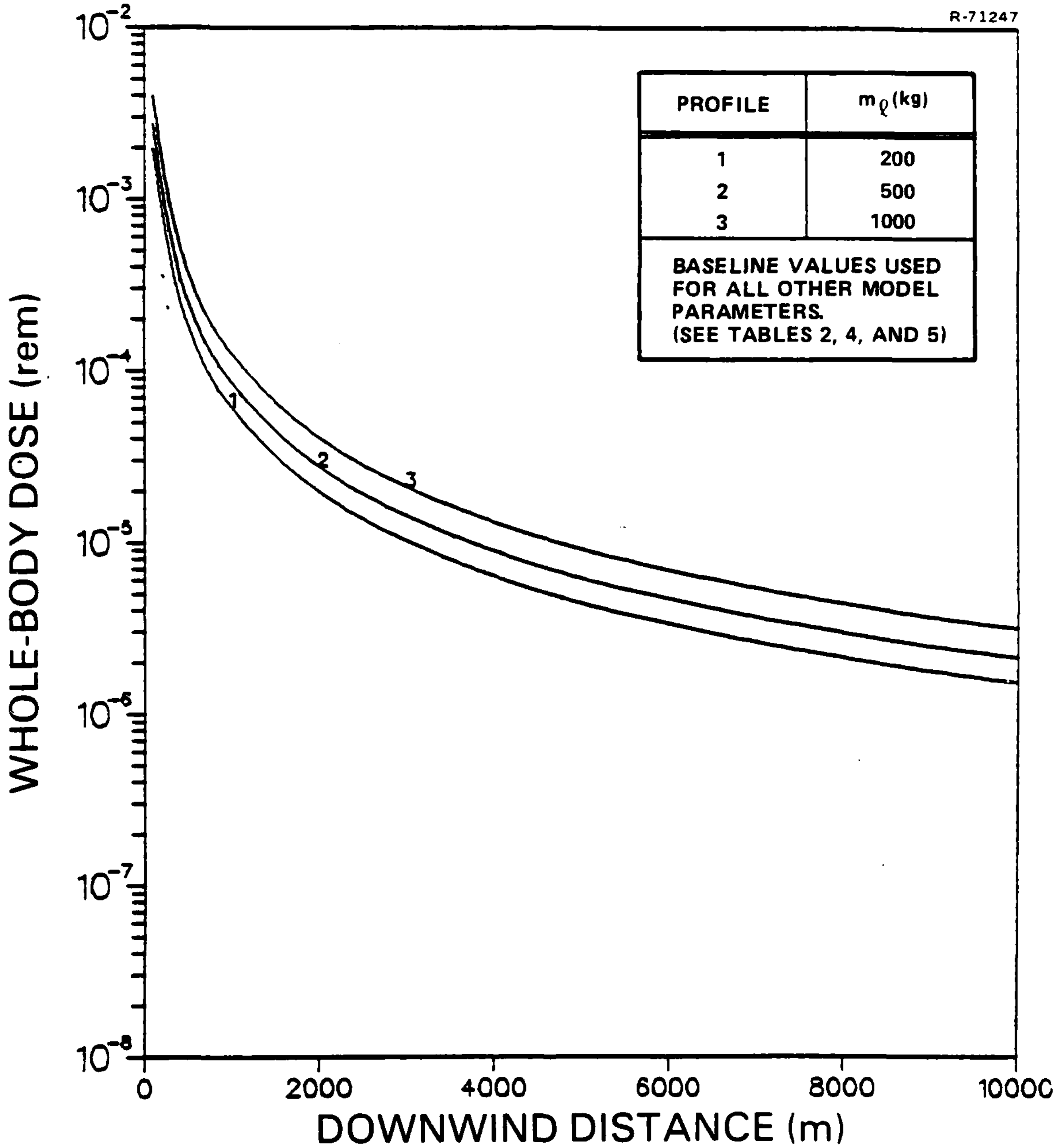


Figure 17 The Effect of Varying Amount of DU Contributing to Ground Concentration on Exposure Estimates

SECTION IV
CONCLUSIONS

In the sensitivity/uncertainty evalution discussed in Section III, it was shown how changing (uncertain) parameter values in TASC's air dispersion and hazard exposure models will impact the resulting estimates of exposure received by the general populace from an airborne release of depleted uranium material. This evaluation identifies those model parameters (singly and in combination) which have the greatest influence on exposure estimates, thus highlighting areas of emphasis for future data collection and parameter identification and providing a clearer understanding of model results for decision-making.

The following conclusions are drawn from this study:

1. The most significant effect on exposure estimates results when the resuspension of depleted airborne particles is high. This effect is accentuated somewhat by higher deposition velocities (which correspond to larger airborne particles).

2. The deposition velocity (singly or in combination) seems to have little effect on exposure estimates when velocities are less than or equal to 0.01 m/sec. (A deposition velocity of 0.01 m/sec is appropriate for airborne uranium particles about 2-5 μm AED (Reference 12), which is the average size of DU particles that become aerosolized during testing (Reference 6).)

3. The nested effect of stability class and wind speed produces an increase in exposure estimates as atmospheric conditions change from unstable (A) to stable (F), resulting in significant differences in exposure estimates between the A and F stability levels.

4. Exposure estimates are most sensitive to varying deposition velocities during stable (F) atmospheric conditions. When the deposition velocity of airborne particles is less than or equal to 0.01 m/sec, exposure estimates change slightly, if at all, under A through E stability conditions. When the deposition velocity is greater than 0.01 m/sec, exposure estimates decrease rapidly as downwind distance increases; this decrease is most dramatic when E or F stability prevails.

5. The use of Task Group Lung Model values for the internal dose commitment factor instead of Reference Man Model values will result in approximately a factor-of-10 increase in the estimated exposure.

6. Varying values for the specific activity of DU have a negligible affect on exposure estimates. All other parameters considered in this study have a minor or small impact on exposure estimates.

REFERENCES

1. Gelinas, R.J., and Vajk, J.P., "Systematic Sensitivity Analysis of Air Quality Models," U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/4-79-035, May 1979.

2. Ensminger, D.A., and Bucci, S.A., "Procedures to Calculate Radiological and Toxicological Exposures from Airborne Releases of Depleted Uranium," The Analytic Sciences Corporation, Reading, Massachusetts, TR-3135-1, October 1980.

3. Pasquill, F., "The Estimation of the Dispersion of Windborne Material," Meteorology Magazine, 90:1063, pp. 33-49, 1961.

4. Slade, D.H. (Editor), "Meteorology and Atomic Energy 1968," U.S. Atomic Energy Commission, Washington, D.C., TID-24190, 1968.

5. "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, D.C., WASH-1400 (NUREG-75/014), October 1975.

6. Glissmeyer, J.A., and Mishima, J., "Characterization of Airborne Uranium from Test Firings of XM774 Ammunition," Pacific Northwest Laboratory, Richland, Washington, PNL-2944, November 1979.

7. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection (Report of Committee 2 on Permissible Dose for Internal Radiation), ICRP Publ. 2, Pergamon Press, London, 1959.

8. "Final Environmental Statement -- Portsmouth Gaseous Diffusion Plant Expansion, Piketon, Ohio," U.S. Energy Research and Development Administration, Washington, D.C., ERDA-1549 (Section 9), September 1977.

9. Waite, D.A., Stoetzel, G.A., and Gilchrist, R.L., "Preliminary Environmental Survey of the B-3 Range and Ford's Farm Area," Pacific Northwest Laboratory, Richland, Washington, PNL-2976, May 1979 (Draft Report).

REFERENCES (Continued)

10. Soldat, J.K., Robinson, N.M., and Baker, D.A., "Models and Computer Codes for Evaluating Environmental Radiation Doses," Battelle, Pacific Northwest Laboratories, Richland, Washington, BNWL-1754, Revised Version, February 7, 1977.

11. Dunning, Jr., D.E., et al., "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities," Oak Ridge National Laboratory, Oak Ridge, Tennessee, NUREG/CR-0150-V-2, November 1979.

12. Momeni, M.H., et al., "The Uranium Dispersion and Dosimetry (UDAD) Code," Argonne National Laboratory, Argonne, Illinois, NUREG/CR-0553, July 1979.

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